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Example applications for transportation infrastructure assessment with UAVs from USDOT and Michigan DOT research

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Evaluating, Mapping, and Managing Unpaved Road Networks Using High-Resolution Aerial Remote Sensing Data

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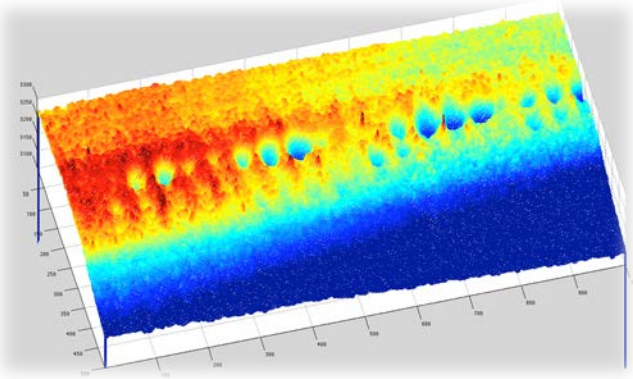
http://www.mtri.org/unpaved/

USDOT Project Goal

Extend available Commercial Remote Sensing and Spatial Information (CRS&SI) tools <u>to enhance and develop an unpaved road assessment system</u> by developing a sensor for, and demonstrating the utility of remote sensing platform(s) for unpaved road assessment.

DISCLAIMER: The views, opinions, findings and conclusions reflected in this presentation are the responsibility of the authors only and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.



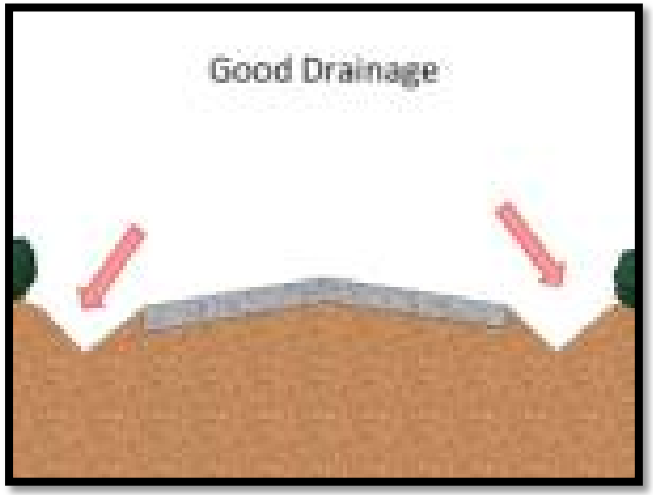
Road Characteristic DETAIL

- **Surface Width**
  - Collected every 10‘ (3m), with a precision of +/- 4” (+/- 10 cm)
- **Cross Section (Loss of Crown)**
  - Facilitates drainage, typically 2% - 4% (up to 6%) vertical change, sloping away from the centerline to the edge.
  - Measure the profile every 10' (3m) along the road direction, able to detect a 1% change across a 9'-wide lane
- **Potholes**
  - <1', 1'-2', 2'-3', >3‘ width bins (<30 cm, 30-61cm, 61-91cm, >91cm)
  - <2”, 2”-4”, >4” depth bins (<5cm, 5-10cm, >10 cm)
- **Ruts**
  - Detect features >5” (13cm), >10' (3m) in length, precision +/-2” (+/-5cm)

Road Characteristic Analysis Detail Cont.

- **Corrugations (Washboarding)**
  - Classify by depth to a precision of +/-1” (2.5cm)
    - <1”, 1”-3”, >3” (<2.5cm, 2.5-7.6cm, >7.6cm)
  - Report total area of the reporting segment affected

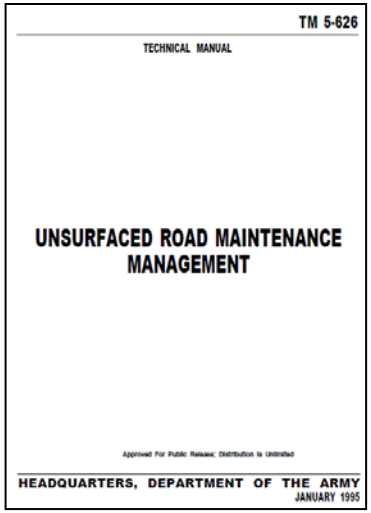
- **Roadside Drainage**
  - System should be able to measure ditch bottom relative to road surface within +/-2” (5cm), if >6”(15 cm) deep
  - Detect the presence of water, elevation +/-2” (5cm), width +/-4” (10cm)



- **Float Aggregate (Berms)**
  - Inverse of ruts

Dept. Army Unsurfaced Road Condition Index (URCI)

- Representative Sample Segments – 2X100’ per mile (2x30m per 1.6km)
- 2 Part Rating System
  - **Density**
    - Percentage of the Sample Area
  - **Severity**
    - Low, Medium, High
- Clear Set of Measurement Requirements
- Realistic Possibility of Collecting Most of the Condition Indicator Parameters
- Potential Applicability to a Wide Variety of U.S. Unpaved Roads
- Endorsed by project Technical Advisory Committee as Effective Rating System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TECHNICAL MANUAL

UNSURFACED ROAD MAINTENANCE MANAGEMENT

Approved For Public Release; Distribution Is Unlimited

HEADQUARTERS, DEPARTMENT OF THE ARMY

JANUARY 1995

Equipment Platforms

- **Bergen Hexacopter**
  - **2nd year – selected demonstration platform**
  - Total flight time: up to 30 minutes with small payloads
  - Weight: 4kg unloaded
  - Maximum Payload: 5kg
  - Easier to fly, less cost than single-rotor
  - Includes autopilot system, stabilized mount that is independent of platform movement, and first person viewer system (altitude, speed, battery life, etc.)

Selected Sensor: Nikon D800

- Nikon D800 – Full-Sized (FX) Sensor
- 36.3 Megapixels
- 4 Frames per Second
- Cost: $3,000

2014 South dakota demonstration imagery

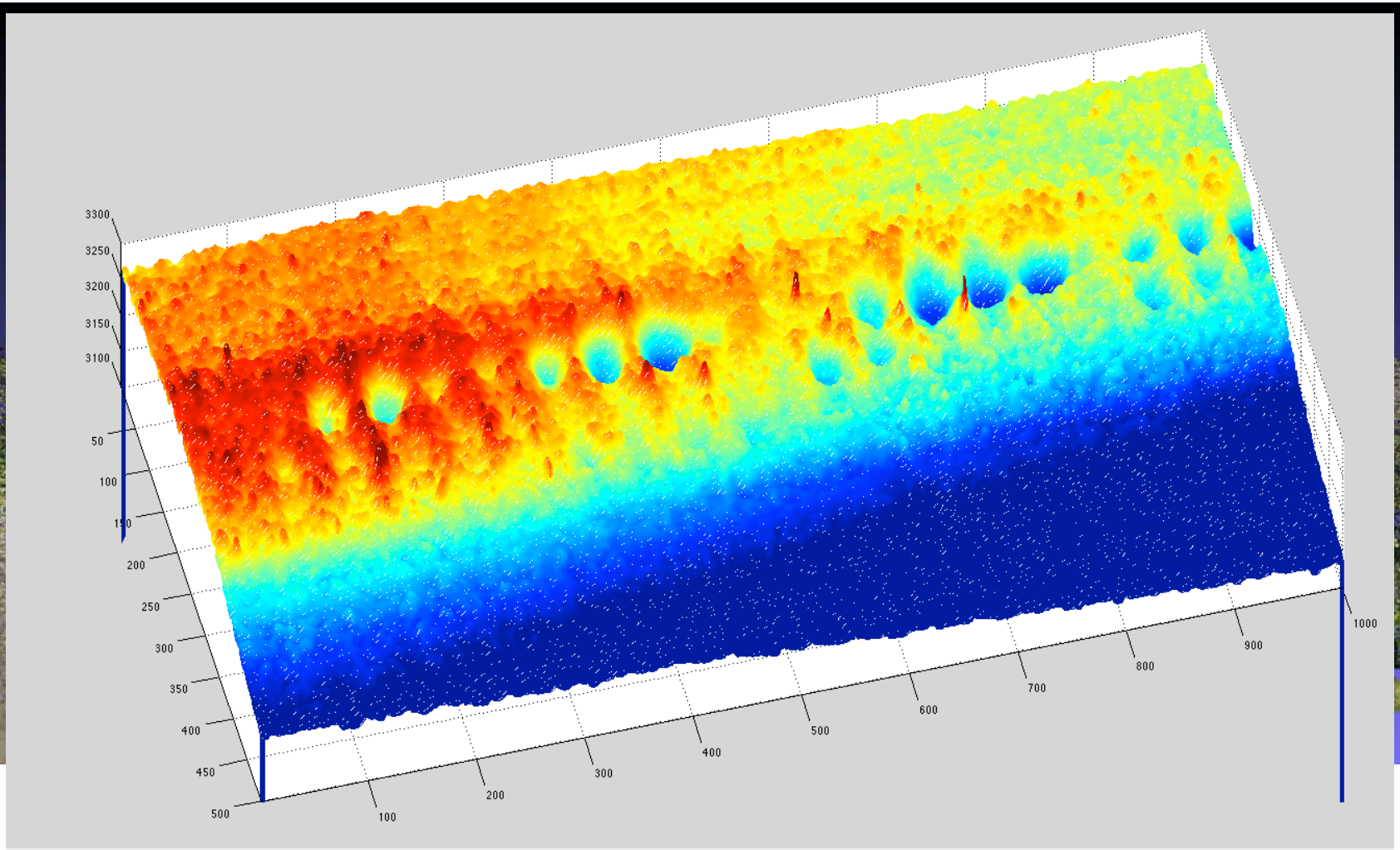
2015 Kansas demonstration photos

Creation and use of 3D data

- Stereo overlapping imagery - used to create 3D roads data using photogrammetric methods (structure from motion, SfM)
  - Open source routines exist to create 3D data using SfM techniques – SIFT, Bundler, PVMS (see Roussi, Colling, Dean, Brooks et al. 2012 project report Deliverable 6-C at http://www.mtri.org/unpaved/)
  - Needed integrating with connecting tools to enable rapid creation of 3D data through the software chain
- Third dimension (height/depth) - critical to calculating the severity of distress. Examples:
  - Are detected potholes in Low (<2”/ <5cm), Medium (2”-4” / 5-10cm), or High Severity >4” depth bins (<5cm, 5-10cm, >10 cm)?
  - What is the amount of crown in categories better than 1%?
  - Distress characterization part of road distress algorithms created to automate matching severity to distress level categories

3D Data Examples

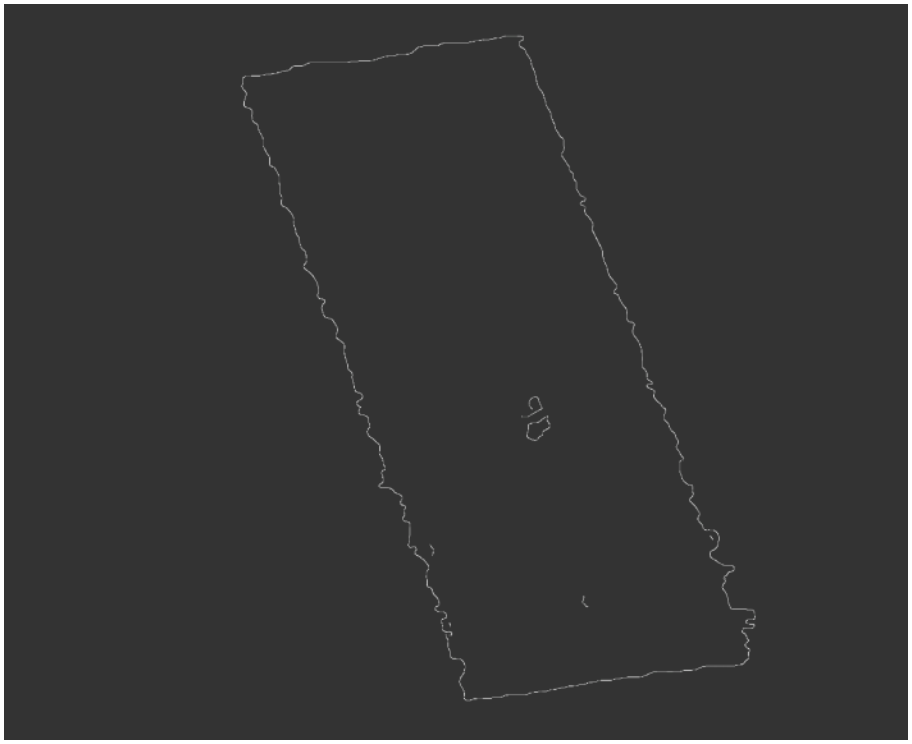
Important to categorizing distresses by severity
Obtaining 0.9 cm ground sample distance



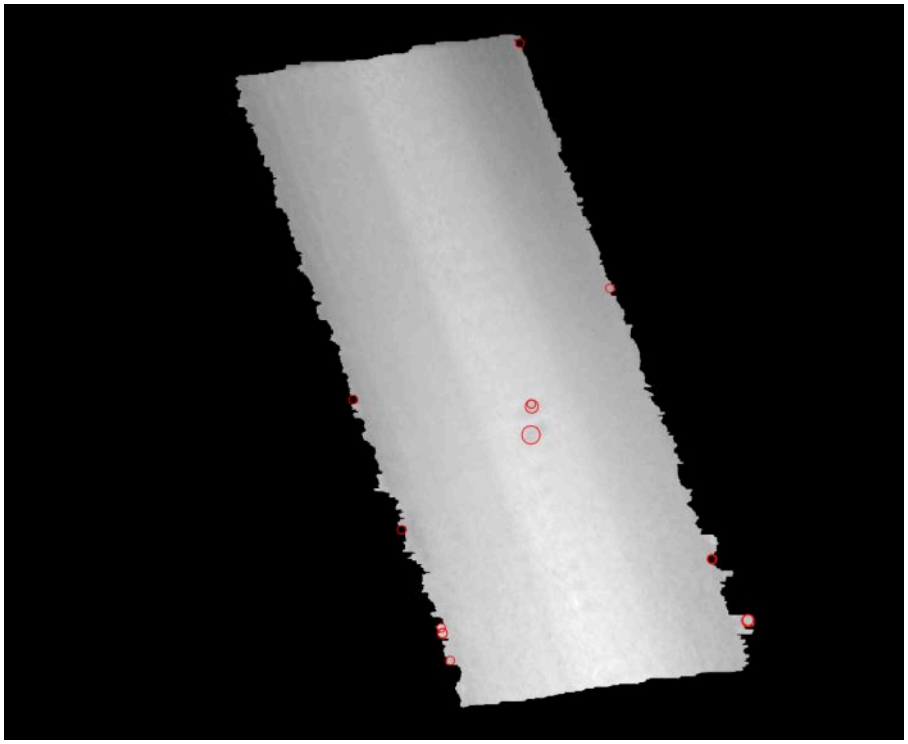
Distress Detection – Potholes

- Canny Edge Detection Used to Locate Edges
- Hough Circle Transform is Used to Locate Potholes

Edge Detection

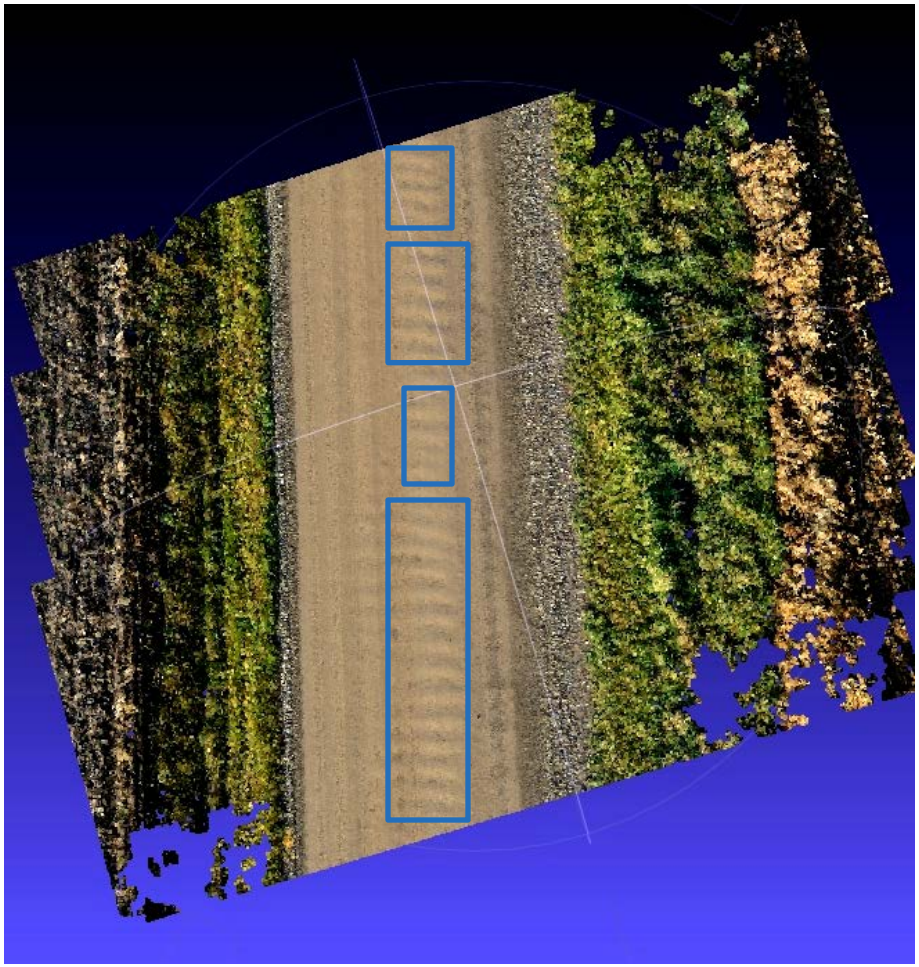


Identified Circles

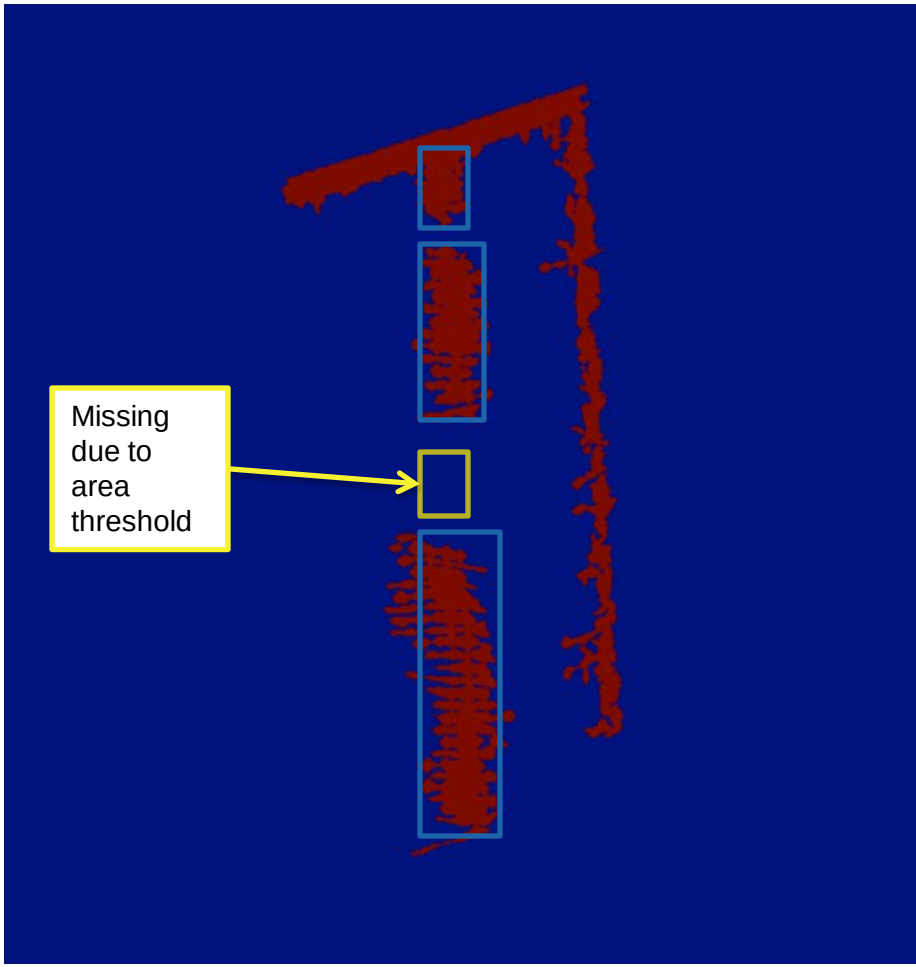


Note: circles near edges ignored.

Distress Detection – Washboarding



Ground Truth Corrugation Area:
19.6 sq. m

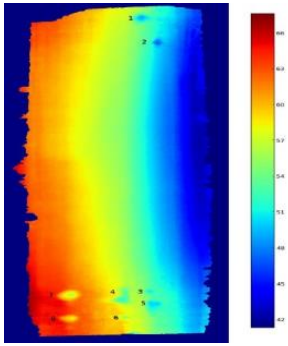


Computed Corrugation Area:
17.2 sq. m

Algorithm Performance Summary

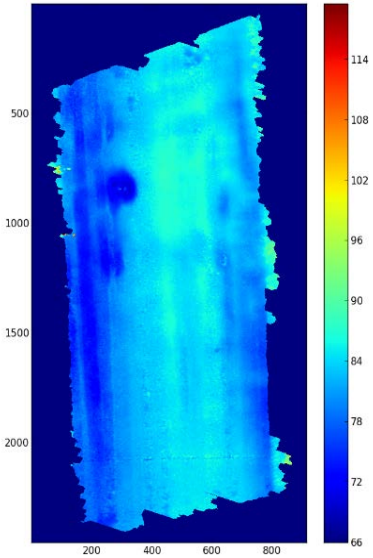
- Pothole: 96% correct

Potholes	Detected Potholes	Potholes misidentified	Probability of Detection	Probability of False Alarm	Probability of Correct Classification
101	96	4	95%	4%	96%



- Crown Damage: (+/- 0.1%)

	Width (cm)	Crown A (cm)	Crown B (cm)	Grade A	Grade B	Min Grade	Damage
1	535	-8.1	10.9	-3.02%	4.07%	-3.02%	H
2	537	-7.4	11.5	-2.75%	4.28%	-2.75%	H
3	545	-7.5	12	-2.75%	4.40%	-2.75%	H
4	519	-7.1	13.1	-2.73%	5.04%	-2.73%	H
5	550	-7.3	12.9	-2.65%	4.69%	-2.65%	H
6	539	-7.5	13	-2.78%	4.82%	-2.78%	H
7	537	-6.4	13	-2.38%	4.84%	-2.38%	H
8	530	-6.1	12.6	-2.30%	4.75%	-2.30%	H
9	525	-5.2	12.6	-1.98%	4.80%	-1.98%	M
10	520	-7.2	11.7	-2.76%	4.50%	-2.76%	H



- Rut Detection:

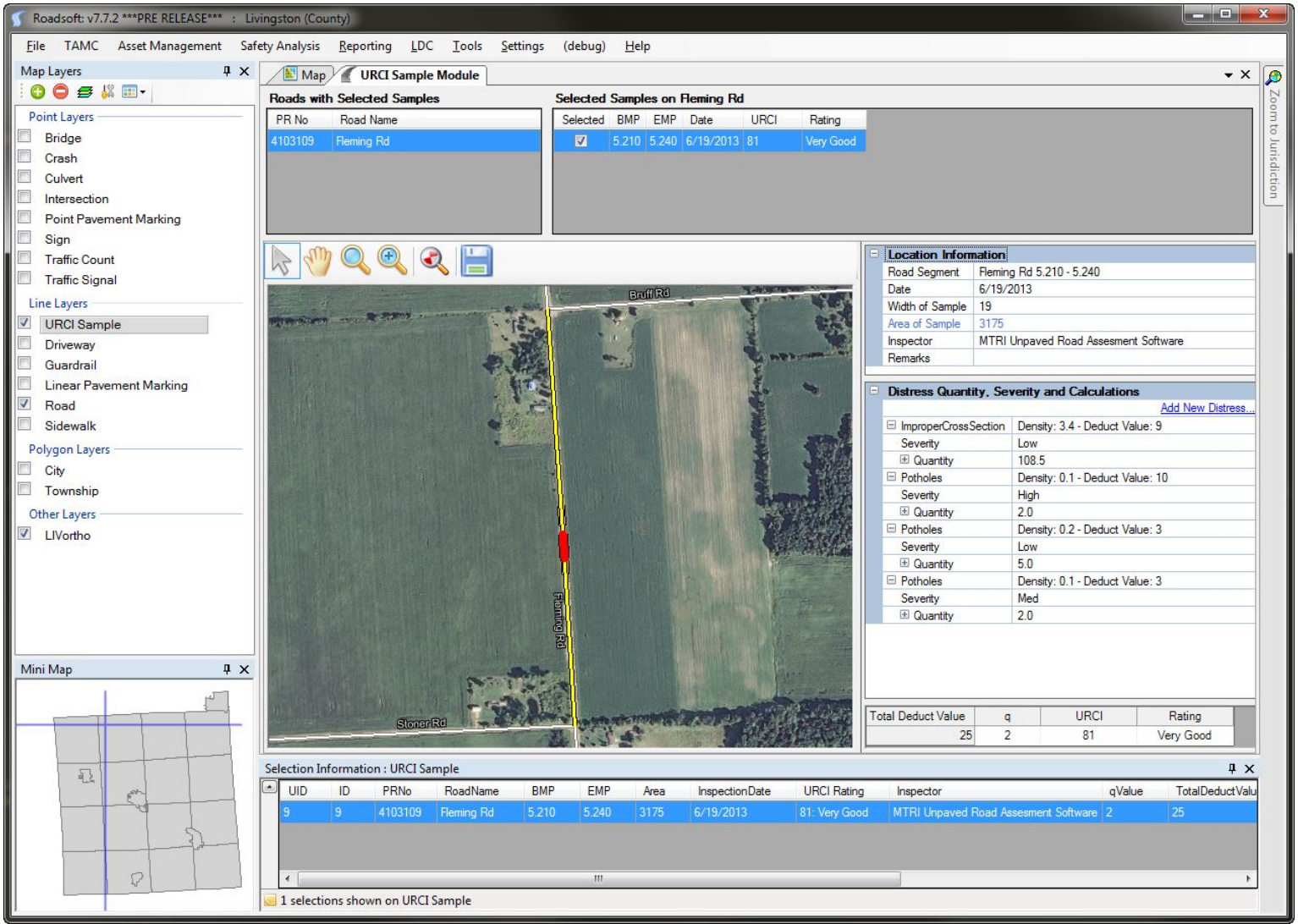
Probability of Detection	Probability of False Alarm
67%	19%

- Corrugation Detection:

Probability of Detection	Probability of False Alarm
100%	38.5%

Summary: *Potholes & crown = excellent; ruts & corrugation – improvement needed*

Analyzed Data Integrated into RoadSoft GIS Decision Support System



Costs – Manual Characterization

Rating Method	$/sample segment	$/Mile
Wyoming Manual URCI (Huntington 2013)	$80	$160*
Manual URCI Ground Truth Collection moderate distress	$100	$200*
Manual URCI Ground Truth Collection high distress	$140	$280*
Army Cold Regions Automated PCI (Cline et al. 2003)	$34.23	$66.10
Army Cold Regions Manual PCI – low total area (Cline et al. 2003)	$50.84	$101.68
UNH/FHWA: RSMS – high productivity estimate (Goodspeed 2011 2013)	NA	$33.65
UNH/FHWA: RSMS – low productivity estimate (Goodspeed 2011 2013)	NA	$65.65
Wyoming Modifications of the PASER Method (Huntington 2011 2013)	NA	$8.55
Michigan PASER Method (CRAM MDOT n.d.)	NA	$8.05

Costs – Remote Sensing

- **UAV, high-resolution camera, and good-quality lens:**
  - Cost per mile rated $30,590/yr/1575 mi/yr = $19.42/mi rated.
  - HOWEVER…two 100-foot measured segments represent one mile of road, so 5,280 ft/200ft is 26.4. Therefore each mile of measured road represents a road network 26 times larger.
  - Therefore cost is **$<u>0.74 per mile</u>,** in addition to the cost of vehicle use ($0.55/mi)
    - 8 hours/day, 3 days/week, 21 week season to collect 300 road-miles of data segments

- Caution must be made for cost comparisons between remote sensing and manual characterization of road conditions due to the resolutions of the outputs; centimeter-by-centimeter analysis of entire road segments is essentially impossible via manual inspection.

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Evaluating the Use of Unmanned Aerial Vehicles for Transportation Purposes

Michigan Tech team members: Colin Brooks (cnbrooks@mtu.edu, 734-604-4196), Thomas Oommen, Timothy C. Havens, Theresa M. Ahlborn, Richard J. Dobson, Dave Dean, Ben Hart, Chris Roussi, Nate Jesse, Rudiger Escobar Wolf, Michelle Wienert, Blaine Stormer, John Behrendt

MDOT program manager: Steve Cook; MDOT Research Manager: André Clover

http://www.mtri.org/mdot_uav.html

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www.mtri.org

Objectives of MDOT Study

- Develop, test, and demonstrate how UAV technology can help provide visual inspections from above for a variety of structures and locations of interest to MDOT
  - Roadway Assets
    - Lighting, signs etc.
  - Confined spaces
    - Pump Stations
    - Entrances to Sewers and Culverts
- Demonstrate how a UAV system can be deployed to monitor traffic operations
- Investigate how UAV based optical and thermal IR technologies can be used to evaluate surface and structural integrity of bridge elements
- Demonstrate how a LiDAR sensor could be used to rapidly assess and inspect transportation infrastructure

Task 1: Develop, Test and Demonstrate How UAV Technology Can Help Provide Visual Inspections

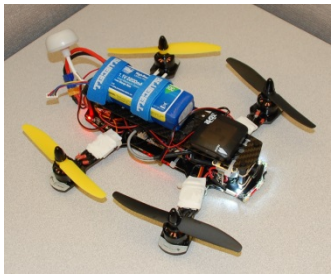
- Multiple Platforms are proposed based upon space and sensor size restrictions
- Appropriate UAV Sensors
  - Digital Cameras
  - Thermal Infrared Sensors
  - LiDAR

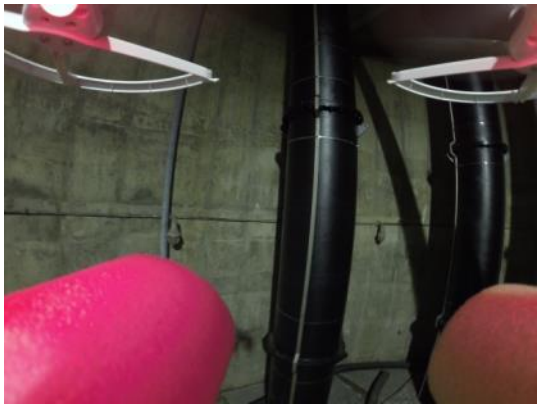
http://www.bergenrc.com/

- Demonstration Locations & Possible Platforms
  - Overhead Infrastructure: Bergen Hexacopter (MI company)
  - Bridge Elements: Medium UAV
  - Pump Stations and Culverts: Micro-UAV

Confined space inspection

- Initial flights - understand capability to fly in confined spaces; later flights - smaller UAVs
  - MDOT Pump Station
  - 4’ culvert (1.2m)
- Is it safe to send a person into the pump station?
  - Eventually: unlit, retrieve through opening
- DJI Phantom 1, Walkera QR W100S, Helimax 1Si; Blackout Mini H Quad ready to fly





Demonstration to SOCCIT – Southeast Oakland County Crash Investigation Team

Task 2: Provide a Demonstration of UAV Based Traffic Monitoring

- Extended Flight Time Required
  - Battery powered helicopter UAVs have max flight times of about 30 minutes (for <$20k ones)
  - Nitro powered helicopters have longer flight times but produce smoke and can leave an oil residue on equipment inc. cameras
- Imagery being collected through HD video or pictures taken with camera (DSLR, etc.)
- A tethered blimp has been proposed for long term traffic monitoring
  - Able to stay aloft for extended periods of time
  - Able to carry a variety of cameras
- Provides near-real time imagery of traffic conditions
  - Imagery transmitted via 4G to internet server

UAVs for Traffic Monitoring

- Aerostats/Blimps
  - Long loitering time on station – up to several days
  - Can be sized to payload requirements
  - Tethered, lower FAA requirements for flight operations, can operate at night
  - Some designs can operate in windy weather
  - Relatively large open area required for launch and recovery

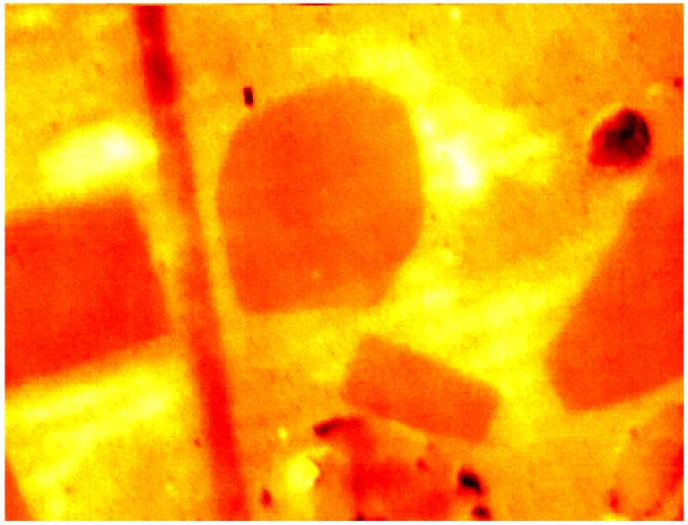
Task 3: Investigate Non-Destructive Evaluation (NDE) of Bridge Elements

- Goals:
  - Develop technology to obtain bridge condition data from UAV platform to supplement routine inspections
  - Surficial condition
  - Non-destructive structural evaluation of bridge element integrity
- Optical and Thermal Sensors will be flown
  - Optical imagery will capture surface defects such as spalls
  - Thermal imagery will capture sub-surface defects such as delaminations
- 3D reconstructions from optical imagery will be used for automated detections of spalls
  - Similar to previous work done with vehicle based data collected and processed under the USDOT Bridge Condition Project (Ahlborn et al.)
- Optical and thermal data will be fused for a complete surface and sub-surface characterization of the bridge elements
- Also - Task 4: Demonstrate UAV Based LiDAR Inspection of Transportation Infrastructure

Bridge asset management & condition assessment imagery: collecting data

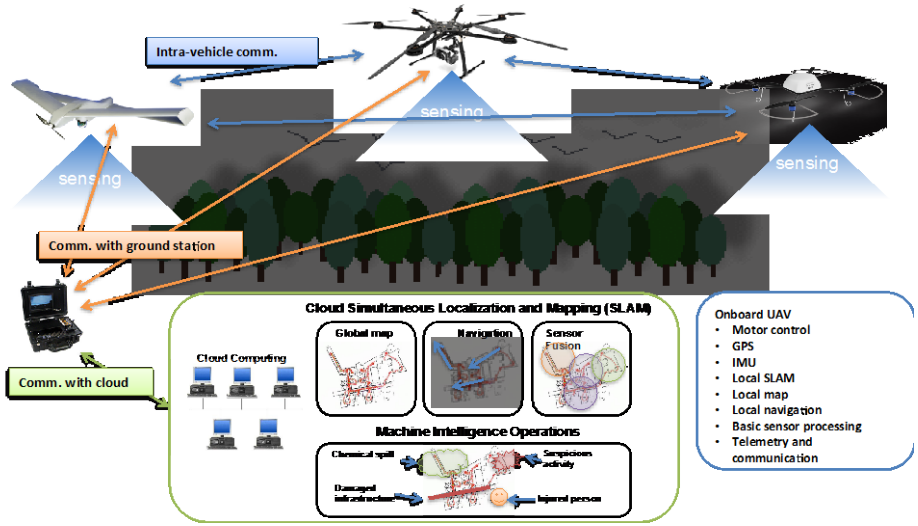
Bridge asset management & condition assessment imagery: examples

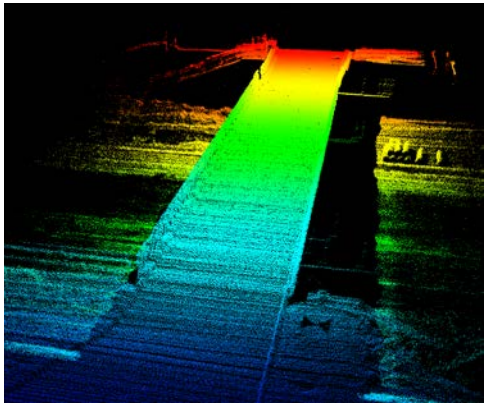
985

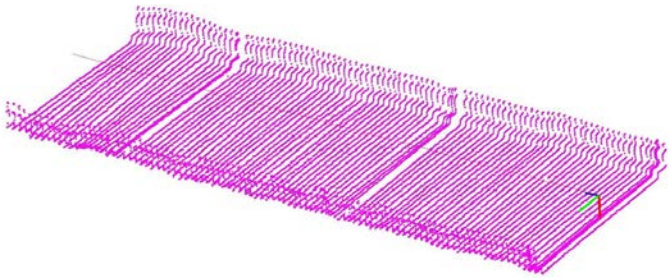


UAV-Based LiDAR

- LiDAR sensor pod developed
  - Hokuyo UTM-30LX LIDAR
  - VectorNAV MEMS IMU
  - Beaglebone Black onboard computer
  - WIFI bridge
  - LiPo battery power
- Three-dimensional Simultaneous Localization and Mapping (SLAM) algorithms developed



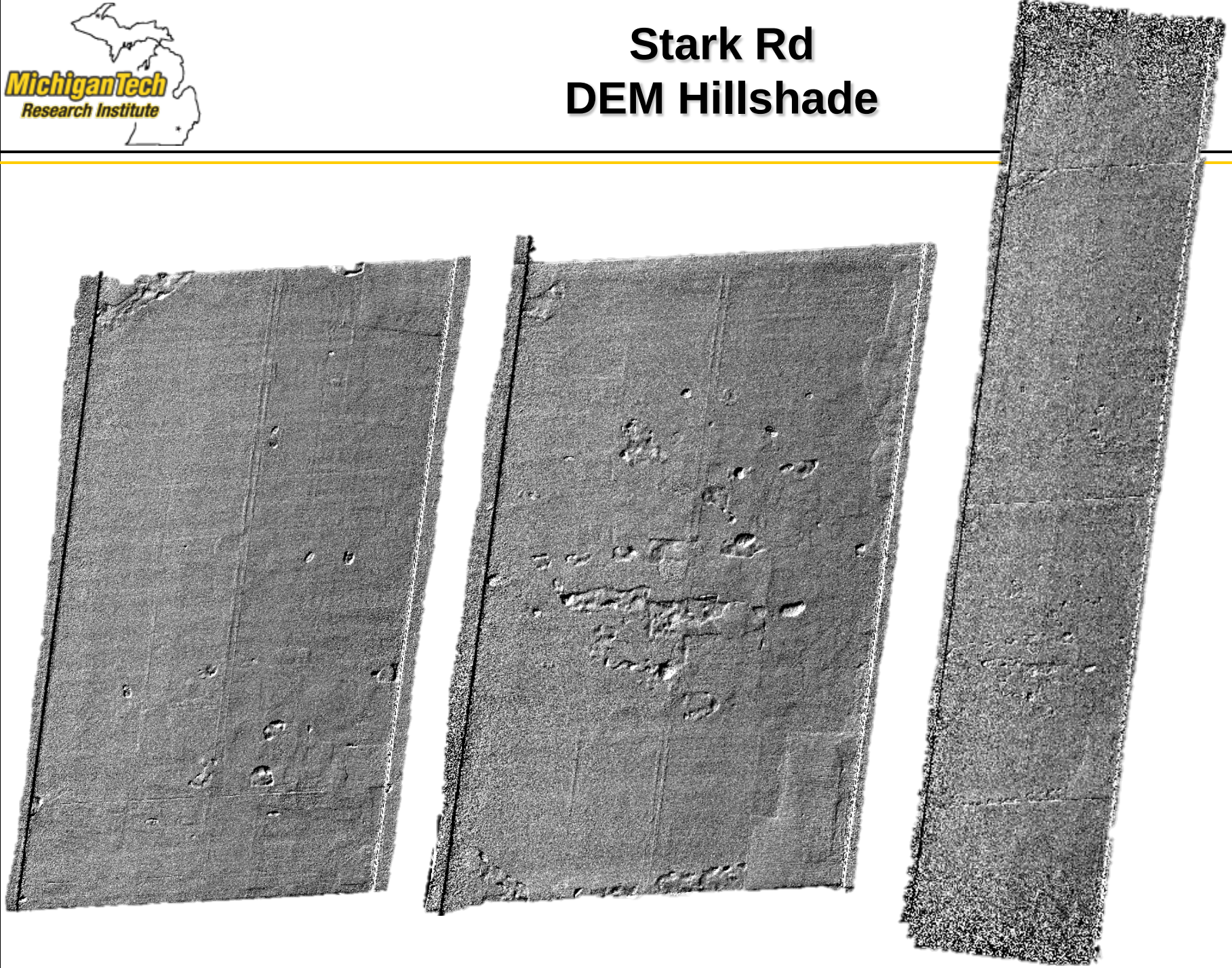




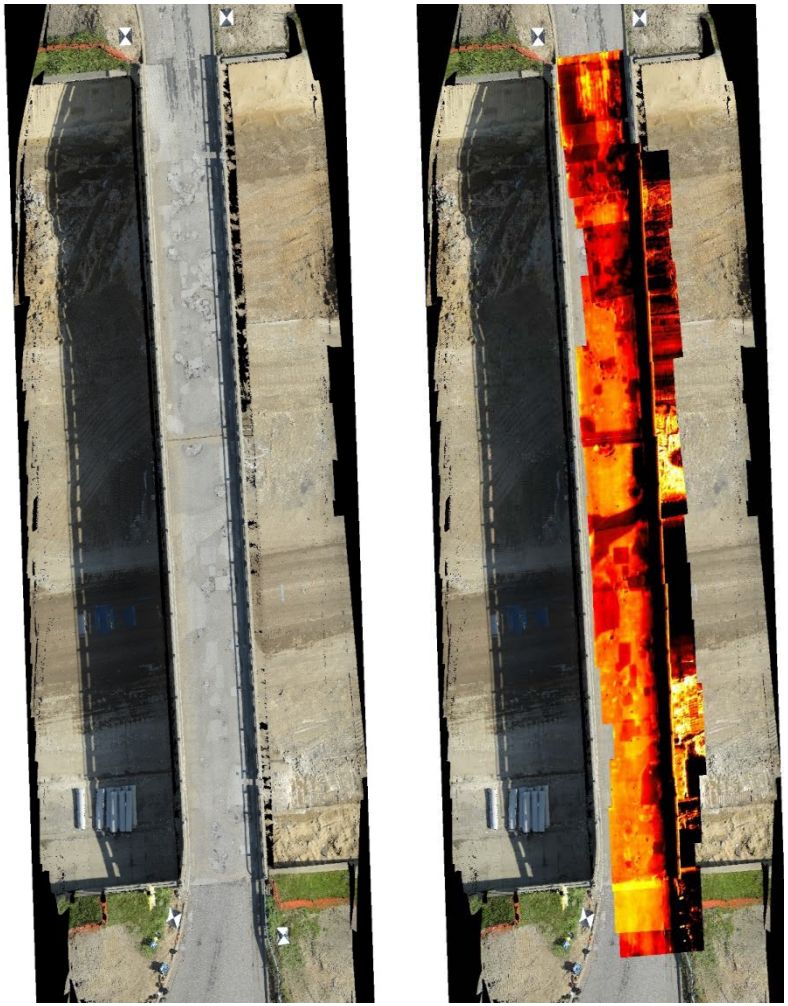
Bridge with linear interpolation assumption

Stark Rd
Orthophoto – 2.5mm

Stark Rd
DEM Hillshade



Combined thermal data for 2 bridges



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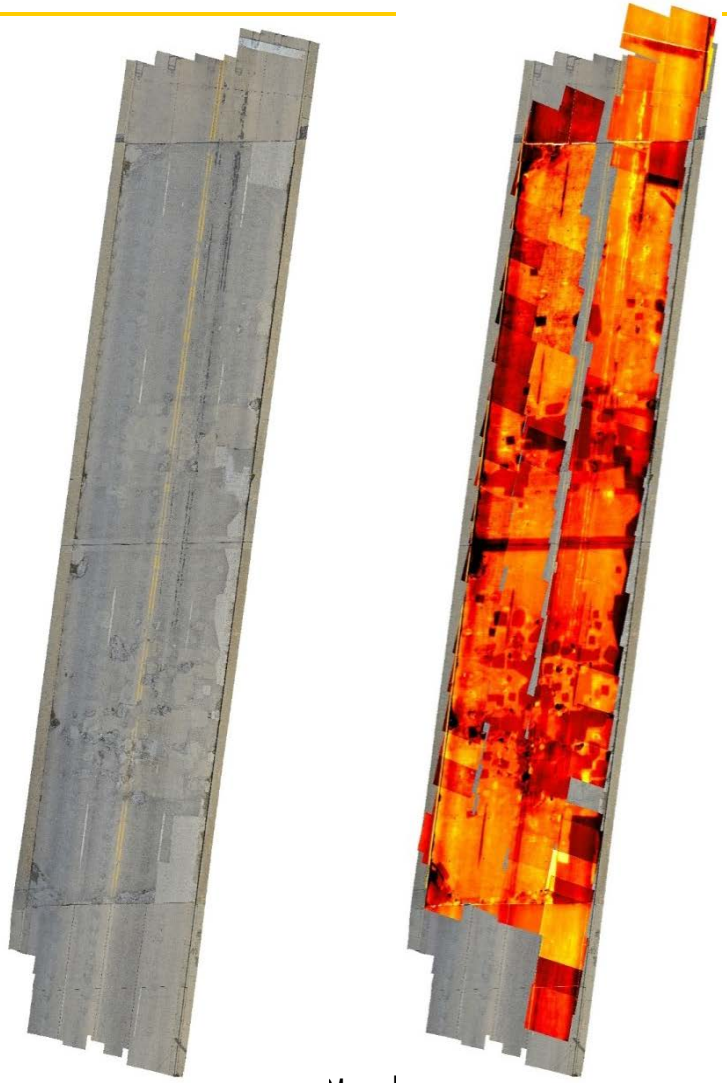
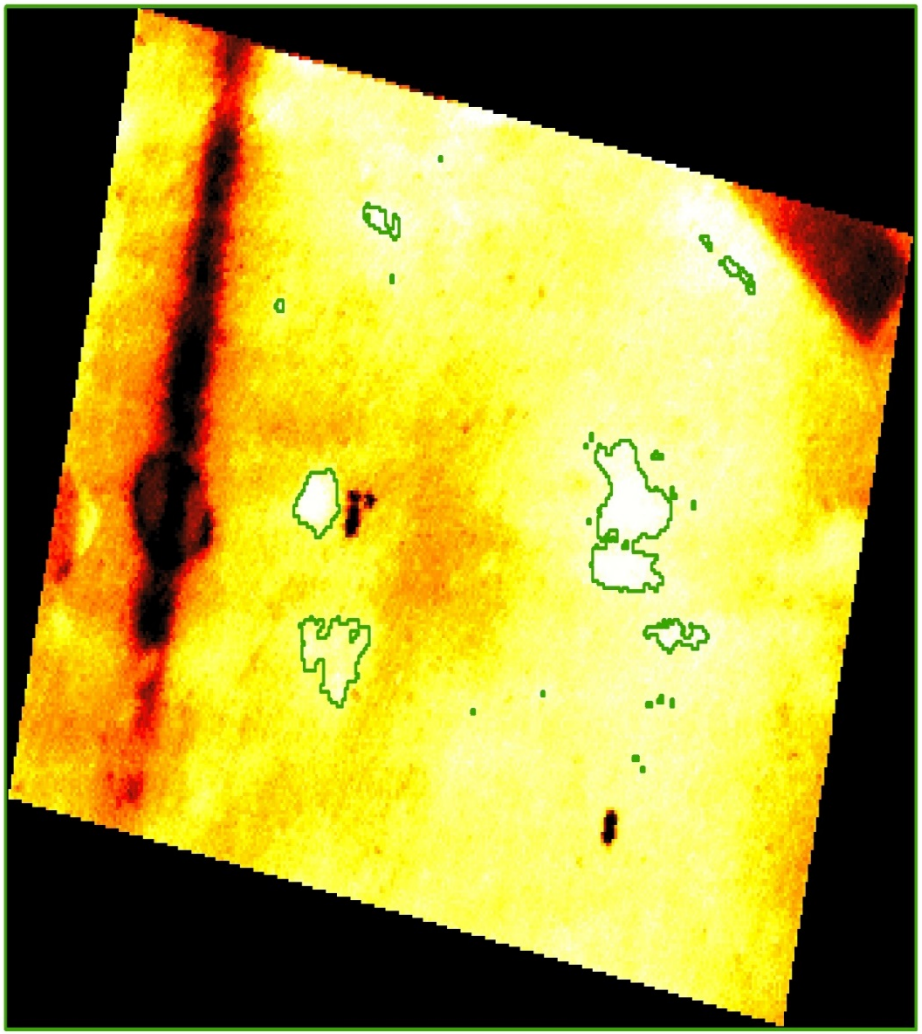


Stark

Automated delamination detection

Delamination should be evident in thermal but not in visible!



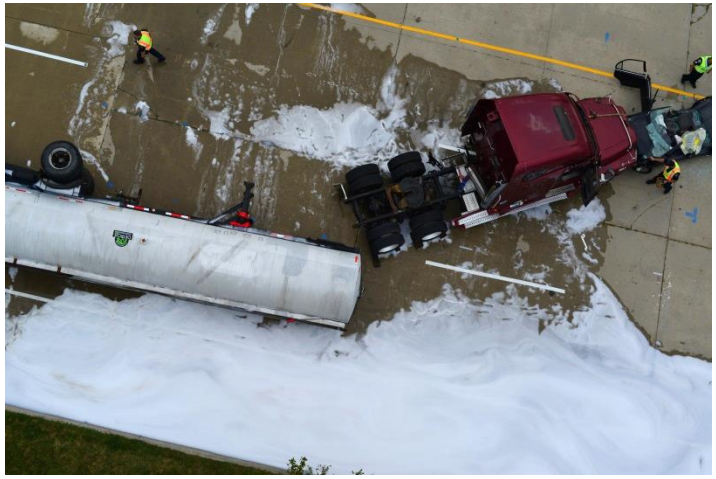
Criteria can be added: eliminate small areas (e. g. single pixels, pixels with low number of neighbors, etc.), look at individual bands, etc.

Only pixels with more than 6 neighbors.

Area = 0.18 m^2

ITS World Congress 2014 demonstrations

- Indoor flights at the indoor Test Track by the Demo Launch area (MTRI booth!)
- Live video feed of Belle Isle from blimp displayed in MDOT Traffic Management Center
- Outdoor demonstrations at Belle Isle (zone 3, near old Casino & GM demo area)



- Funded through MDOT grant, 2013-067 / Auth. 1 / OR13-008
- http://www.mtri.org/mdot_uav.html

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